

11-12-2005

A vision system for providing the blind with 3D colour perception of the environment

S. Meers

University of Wollongong, meers@uow.edu.au

Koren Ward

University of Wollongong, koren@uow.edu.au

Follow this and additional works at: <https://ro.uow.edu.au/infopapers>



Part of the [Physical Sciences and Mathematics Commons](#)

Recommended Citation

Meers, S. and Ward, Koren: A vision system for providing the blind with 3D colour perception of the environment 2005.

<https://ro.uow.edu.au/infopapers/436>

A vision system for providing the blind with 3D colour perception of the environment

Abstract

Although various attempts have been made at providing the blind with substitute visual perception, no existing method provides useful colour perception of the environment. This paper describes a substitute vision system which provides perception of the three-dimensional profile and colour of the surrounding environment via haptic sensations alone. This is aimed at allowing visually-impaired people to avoid obstacles and navigate the environment by recognising landmarks by their colour and profile. The prototype system uses stereo video cameras to capture colour images of the environment from which a disparity depth map can be calculated. The depth map is sampled into ten range readings, which are communicated to the user via electro-neural pulses in their fingers. The intensity of the pulses is directly proportional to the distance sampled in the corresponding depth map region. Also, the pulse frequency is determined by the predominate colour in that region. Thus by imagining the fingers are extended in the forward direction, the user can feel the distance to objects and their colour based on the approximate direction pointed by each finger. This paper focuses on describing the method employed in achieving 3D colour perception via haptic stimulation and how this form of perception can be used to navigate familiar environments.

Keywords

Substitute vision, colour, disparity, electro-neural vision, TENS, electro-tactile, stereo cameras

Disciplines

Physical Sciences and Mathematics

Publication Details

This paper was originally published as: Meers, S & Ward, K, A vision system for providing the blind with 3D colour perception of the environment, Proceedings of the Asia-Pacific Workshop on Visual Information Processing, Hong Kong, December 2005.

A VISION SYSTEM FOR PROVIDING THE BLIND WITH 3D COLOUR PERCEPTION OF THE ENVIRONMENT

SIMON MEERS, KOREN WARD

School of IT and Computer Science, University of Wollongong, Australia
E-mail: meers@uow.edu.au, koren@uow.edu.au

Abstract:

Although various attempts have been made at providing the blind with substitute visual perception, no existing method provides useful colour perception of the environment. This paper describes a substitute vision system which provides perception of the three-dimensional profile and colour of the surrounding environment via haptic sensations alone. This is aimed at allowing visually-impaired people to avoid obstacles and navigate the environment by recognising landmarks by their colour and profile. The prototype system uses stereo video cameras to capture colour images of the environment from which a disparity depth map can be calculated. The depth map is sampled into ten range readings, which are communicated to the user via electro-neural pulses in their fingers. The intensity of the pulses is directly proportional to the distance sampled in the corresponding depth map region. Also, the pulse frequency is determined by the predominate colour in that region. Thus by imagining the fingers are extended in the forward direction, the user can feel the distance to objects and their colour based on the approximate direction pointed by each finger. This paper focuses on describing the method employed in achieving 3D colour perception via haptic stimulation and how this form of perception can be used to navigate familiar environments.

Keywords:

Substitute vision; colour; disparity; electro-neural vision; TENS; electro-tactile; stereo cameras.

1. Introduction

To overcome some of the disabling effects of blindness, we have developed a device which enables perception of the three-dimensional profile and colour of the surrounding environment via haptic sensory inputs. This device is intended to allow visually-impaired people to perceive the 3D structure of their environment and navigate by recognising landmarks by their colour and profile. Our prototype Electro-Neural Vision System (ENVS) uses stereo video cameras to capture colour images of the environment from which a disparity depth map can be calculated. The depth map is sampled into ten range

readings, which are communicated to the user via electro-neural pulses in the fingers. The intensity of each pulse is directly proportional to the distance sampled in the corresponding depth map region. Also, the pulse frequency is determined by the predominate colour in that region. Thus by imagining that the fingers are extended in front of the abdomen, the user can feel the distance to and colour of objects approximately pointed at by each finger. Figure 1 shows a user wearing the ENVS prototype.

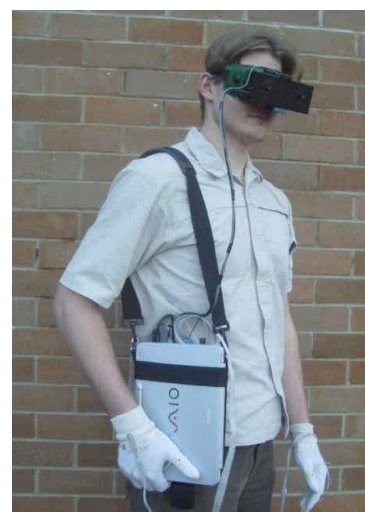


Figure 1. The Electro-Neural Vision System Prototype

In section 2 of this paper we provide a brief overview of previous research and development of substitute vision systems for the blind. Section 3 outlines the implementation of the ENVS, including our most recent work on combined spatial and colour perception. Section 4 describes some experiments which demonstrate how the ENVS can be used to navigate the environment by recognising certain objects by their colour without any use of the eyes. Concluding remarks are provided in Section 5, together with a brief discussion of further work to be done.

2. Background

A number of researchers are attempting to develop bionic vision for the blind, see [1], [2] and [3]. This is comprised of artificial silicon retinas, or external cameras, that stimulate the optic nerve or visual cortex via implanted electrodes. The only commercially available artificial vision implant, at present, is the Dobelle Implant [4]. This implant provides visual perception in the form of perceived points of light that change in response to varying images. However, these points of light bear little resemblance to the observed environment, which provides little assistance to the blind. Even if more successful results are achieved with implants in the not-so-distant future, many blind people may not have access to implants due to their high cost and the expertise required to surgically implant such devices. Furthermore, some forms of blindness, for example brain or optic nerve damage, may be unsuitable for implants.

Various wearable devices have been developed for providing the blind with some means of sensing or visualising the environment. For example, Meijer's vOICE [5] compresses a camera image into a coarse 2D array of greyscale values and delivers this information to the ears as a sequence of sounds with varying frequency. However, the limited bandwidth of sound and difficulty in interpreting images by this means provides little, if any, visual cognition.

Sonar mobility aids for the blind have been developed by Kay [6]. Kay's system delivers frequency modulated sounds, which represent an object's distance by the pitch of the generated sound and the object's surface texture by the timbre of the sound delivered to the headphones. However, to an inexperienced user, these combined sounds can be confusing and difficult to interpret. Also, the sonar beam from these systems is very specular in that it can be reflected off many surfaces or absorbed resulting in uncertain perception. However, Kay's sonar blind aids can help to identify landmarks by resolving some object features (i.e. resolution, texture, parallax, etc.) and can facilitate some degree of an object's classification to experienced users.

A major disadvantage of auditory substitute vision systems is that they can diminish a blind person's capacity to hear sounds in the environment, such as voices, traffic, walking, etc. Consequently, these devices are not widely used in public places because they can reduce a blind person's auditory perception of the environment and could potentially cause harm or injury if impending danger is not detected via hearing.

Electro-tactile displays for interpreting the shape of images on a computer screen with the fingers, tongue or

abdomen have been developed by Kaczmarek et al [7]. These displays work by mapping black and white pixels to a matrix of closely-spaced pulsated electrodes which can be felt by the fingers. Although these electro-tactile displays can give a blind user the capacity to recognise the shape of certain objects, such as black alphabetic characters on a white background, they do not provide the user with any useful 3D perception of the environment which is necessary for navigation, localisation and obstacle avoidance.

Previously [8], the ENVS has demonstrated that it can provide a practical, intuitive means of perceiving the 3D structure of the environment in a way that does not reduce the user's capacity to hear sounds in the environment. In this paper we provide details and results of how colour visual information can also be detected by the ENVS and delivered to the user via electro-tactile stimulation. It has been demonstrated that this form of 3D colour perception enhances the user's ability to recognise certain locations as significant landmarks which provides increased localisation and navigational skills. In the following section we briefly provide a description of the ENVS hardware and the method utilised for delivering colour information to the ENVS electro-tactile interface.

3. ENVS Description

The components of the ENVS are shown in Figure 2. The ENVS comprises a stereo video camera headset for obtaining video and depth information from the environment; a laptop computer; a Transcutaneous Electro-Neural Stimulation (TENS) unit for converting the output from the computer into appropriate electrical pulses that can be felt via the skin; and special gloves fitted with electrodes for delivering the electrical pulses to the fingers.



Figure 2. ENVS Components

3.1 ENVS 3D Perception

Figure 3 shows the ENVS hardware. The prototype stereo camera headset is designed to simulate blindness by preventing light from entering the user's eyes. The cameras capture two simultaneous images from slightly different perspectives, just like human eyes. Using a stereo disparity algorithm, the ENVS software can calculate a depth map indicating the distance to each point in the image. Visually, this data can quite clearly indicate the depth profile of the environment, though the next problem lies in communicating this data to the user via non-visual means.



Figure 3. ENVS Hardware

The communication bandwidth of our prototype system is limited to ten electro-neural pulse outputs – one to each finger. To compress the depth map, ten rectangular regions are arranged within the image, and depths are sampled from within each region. The sampled depth value is then converted into an electro-neural pulse of proportional intensity by the TENS unit. The intensity of the signal is controlled by adjusting the pulse width of the TENS output signal. The frequency of the signal is used to represent any colour information for that region; this is discussed in the next section. The TENS signals are delivered to the fingers via the electrodes in the gloves. To achieve electrical conductivity between the fingers and the electrodes, a small amount of conductive gel is applied to the fingers.

The prototype ENVS has a screen based interface to allow the parameters of the disparity algorithm, vision processing, data sampling method and TENS output to be changed for experimentation purposes. A typical screenshot of the ENVS control panel is shown in Figure 4.



Figure 4. ENVS Software Interface

The top left image displays a stereo camera image, while the top right image displays the calculated corresponding depth map. In this map, lighter pixels represent closer objects, while darker pixels indicate more distant objects. Black regions are areas that indicate that the object is either out of range or unable to be measured due to a lack of features (edges, colour and texture changes, etc). This featureless surface problem is inherent in stereo disparity calculations and can make it difficult for the ENVS to determine the range of some surfaces. We hope to overcome this problem by adding additional sensors to the stereo head such as infrared or sonar sensors.

The disparity image in Figure 4 also shows the ten rectangular sample regions used to derive the finger pulses from. The size and arrangement of these regions is adjustable. The minimum depth sampled within each region is displayed on the histogram at the bottom-left of the control panel shown in Figure 4. This indicates the intensity of the TENS output signals and represent the coarse depth profile of the environment as sampled across the ten regions. When fused with motion the user very quickly learns to interpret the intensity of these signals as the distance to objects in the corresponding regions of the environment. Thus by 'looking around' the environment with the ENVS headset, the user can build a mental map of the 3D profile of their surroundings as well as the colour of certain objects. Using a 1000 MHz Pentium computer we were able to achieve a frame rate of 15 frames per second, which proved more than adequate for our experiments.

3.2 ENVS Colour Perception

Although environmental range readings can enable blind users to avoid obstacles and recognise their location by perceiving the relative profile of the surrounding environment, a considerable improvement in localisation, navigation and object recognition can be achieved by incorporating colour perception into the ENVS. Colour perception is important because it can facilitate the recognition of significant objects which can serve as landmarks when navigating the environment.

To encode colour perception into the ENVS, the frequency of the electrical signals delivered to the fingers was adjusted according to the corresponding colour sample. We considered two main methods of achieving colour perception. One method was to represent the continuous colour spectrum with the entire available frequency bandwidth of the ENVS signals. Thus red objects detected by the ENVS would be represented with low frequency signals, violet colours would be represented with high frequency signals and any colours between these limits would be represented with a corresponding proportionate frequency. The second method was to only represent significant colours with specific allocated frequencies via a lookup table.

It was found that the most useful frequencies for delivering depth and colour information to the user via transcutaneous electro-neural stimulation were frequencies between 10 and 120Hz. Frequencies above this range tended to result in nerves becoming insensitive by adapting to the stimulation. Frequencies below this range tended to be too slow to respond to changed input. Consequently, mapping the entire colour spectrum to the frequency bandwidth available to the ENVS signals proved infeasible due to the limited bandwidth available. Furthermore, ENVS experiments involving detection and delivery of all colours within a specific environment via frequencies proved too much for accurate interpretation of the range and colour information. Rapid changes in frequency often made the intensity difficult to determine accurately and vice versa.

Due to the infeasibility of mapping the entire colour spectrum to frequencies, an eight-entry lookup table was implemented in the ENVS for mapping significant colours, selectable from the environment, to selectable frequencies. Significant colours are colours possessed by objects in the user's familiar environment that can aid the user in locating their position in the environment or locating regularly used items – for example, doors, kitchen table, refrigerator, pets, people (i.e. skin colour), home, etc. Although these colours may be taken from regularly encountered environments, such as the home or workplace, they are also likely to be

often encountered on objects in unfamiliar environments which can be used as beacons or landmarks to aid in navigation.

4. Experimental Results

We conducted a number of experiments to determine if users could navigate indoor environments without using the eyes by perceiving the 3D structure of the environment and by recognising the location of landmarks by their colour using the ENVS. The users who participated in the experiments were familiar with the laboratory environment and had at least one hour practise at using the ENVS. At this stage we have not conducted experiments with blind subjects. To simulate blindness with sighted users the stereo camera headset was designed to fit over the user's eyes so that no light whatsoever could enter the eyes. To avoid the possibility of users remembering any sighted positions of objects in the environment prior to conducting trials, users were blindfolded and lead some considerable distance to the starting point of each experiment.

4.1. Navigating Corridors

Our first test was to determine if the ENVS users could navigate the corridor and find the correct door leading into the laboratory from a location in another wing of the building. Prior to conducting the trials users were familiarised with the entrance to the laboratory and had practiced negotiating the corridor using the ENVS.

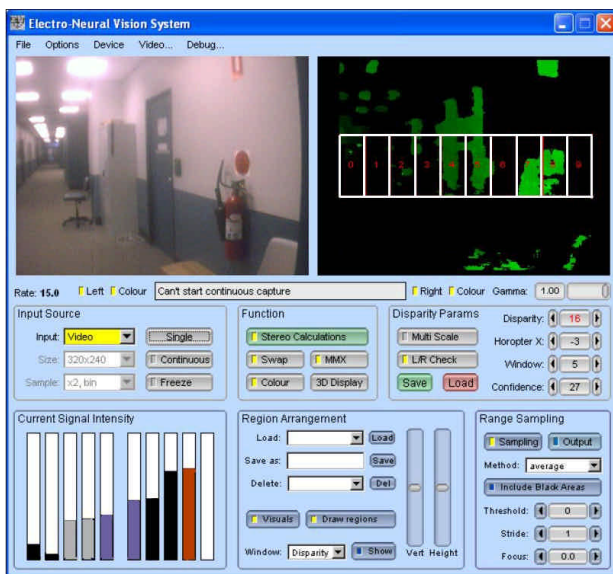
The lab entrance was characterised by having a blue door with a red fire extinguisher mounted on the wall to the right of the door. To the left of the door, was a grey cabinet. The colour of the door, fire extinguisher and cabinet were stored in the ENVS as familiar colours and given distinguishable frequencies. Other colours were also stored in the ENVS as familiar colours, however these colours were not present in the corridor environment and not involved in this experiment. Figure 5 shows a photo of a user observing the entrance of the laboratory with the ENVS (see Fig. 5a) and a simultaneous screenshot of the ENVS control panel (see Fig. 5b). The level of stimulation delivered to the fingers can be seen on the histogram at the bottom-left of Figure 5b. As close range readings stimulate the fingers more than far range readings, the finger stimulation levels felt by the user at this instant makes it clear he is observing a wall on his right.

Furthermore, the three familiar colours of the door, fire extinguisher and cabinet can also be seen in the range histogram of Figure 5b. This indicates that the ENVS has detected these familiar colours and is indicating this to the

user by stimulating the left middle finger, left pointer finger, both thumbs and the right ring finger with frequencies corresponding to the detected familiar colours.



(a)



(b)

Figure 5. (a) An ENVS user negotiating the corridor. (b) The ENVS screen dump showing the detected familiar colours and the observed profile of the left corridor wall.

After being familiarised with the laboratory entrance, the ENVS users were lead to a location in another wing of the building and asked to find their way back to the lab by using only the ENVS. We found the ENVS users could competently negotiate the corridor, locate the laboratory

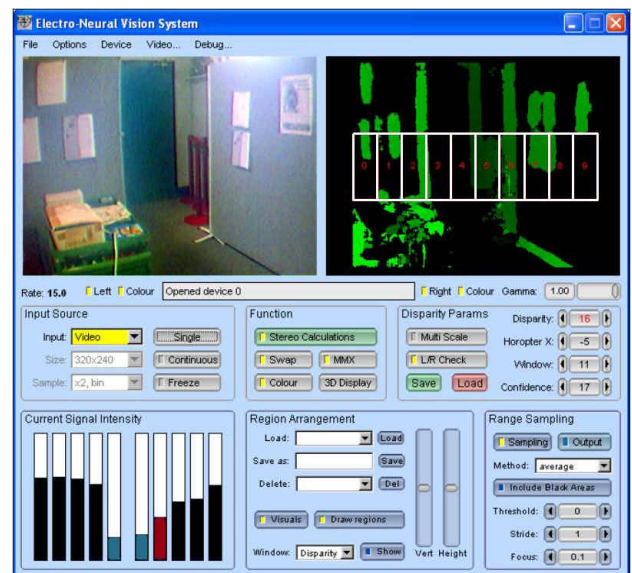
entrance and enter the laboratory unassisted and without difficulty, demonstrating the potential of this form of colour and 3D perception as an aid for the visually disabled.

4.2. Navigating the Laboratory

Experiments were also performed within the laboratory (see Figure 6) to determine if the ENVS users could recognise their location and navigate the laboratory to the doorway without using the eyes or other blind aids.



(a)



(b)

Figure 6. (a) An ENVS user surveying the lab (b) The associated ENVS screen dump.

The colours of a number of significant objects were encoded into the ENVS as familiar colours. These included the blue door, a red barrier stand located near the door, the grey partitions in the laboratory and the grey computer and printer housings located throughout the laboratory.

Before being given any navigational tasks in the laboratory, each user was given approximately three minutes with the ENVS to become familiarised with the doorway vicinity and other objects that possessed familiar colours that were stored in the ENVS. To ensure that the starting location and direction was unknown to the ENVS users, each user was rotated a number of times on a swivel chair and moved to an undisclosed location in the laboratory immediately after being fitted with the ENVS. Furthermore, to make the task more difficult, the doorway happens to be concealed from view from most positions in the laboratory by partitions. Consequently, users had the added task of first locating their position using other familiar coloured landmarks and the perceived profile of the laboratory before deciding on which direction to head toward the door.

It was found all users were able to quickly determine their location within the laboratory based on the perceived profile of the environment and the location of familiar objects, (mostly the location of the computers and printer in this case). Subsequently, all users were able to approach the door, identify it by its familiar colour (as well as the barrier stand near the door) and proceed to the door. Figure 6 shows a photo of a user observing the laboratory door with the ENVS (see Fig. 6a) and a simultaneous screenshot of the ENVS control panel (see Fig. 6b). The level of stimulation delivered to the fingers and the detected familiar colours can be seen on the histogram at the bottom-left of Figure 6b.

5. Conclusion

This paper describes a substitute vision system for delivering 3D colour perception to the user via an electro-tactile user interface. By using haptic communication instead of audio feedback, the ENVS has advantages over existing audio substitute vision systems which occupy the user's hearing. Our experiments indicate that the ENVS is able to provide the user with the ability to intuitively perceive the 3D spatial profile of the surrounding environment and identify landmarks based on their colour. This demonstrates that combined communication of range and colour information via electro-tactile pulses is effective. However, mapping the entire colour spectrum to frequencies and delivering this to the fingers simultaneously proved difficult for the user to

interpret. Instead, the use of significant colours selected from the environment which are allocated to differentiable frequencies, was found to be more effective. This form of colour perception enhances the user's ability to navigate the environment by enabling the user to recognise significant landmarks based on their colour.

This paper also outlined a number of limitations of the ENVS due to hardware and software constraints. The main limitations are the inability of stereo disparity cameras to detect featureless surfaces and the limited communication bandwidth available to the user. To overcome these limitations we intend utilising additional range sensors capable of detecting featureless surfaces, modulating the pulses to increase the differentiable sensations available to the user, and developing alternative electro-tactile communication devices. We are also experimenting with the integration of GPS technology for additional outdoor navigational capabilities.

References

- [1] Wyatt, J.L. and Rizzo, J.F., Ocular Implants for the Blind, *IEEE Spectrum*, Vol.33, pp.47-53, May 1996.
- [2] Rizzo, J.F. and Wyatt, J.L., Prospects for a Visual Prosthesis, *Neuroscientist*, Vol.3, pp.251-262, July 1997.
- [3] Rizzo, J.F. and Wyatt, J.L., Retinal Prosthesis, in: *Age-Related Macular Degeneration*, J.W. Berger, S.L. Fine and M.G. Maguire, eds., Mosby, St. Louis, pp. 413 - 432. 1998.
- [4] Dobelle, W. Artificial Vision for the Blind by Connecting a Television Camera to the Visual Cortex, *American Society of Artificial Internal Organs Journal*, January/February 2000.
- [5] Meijer, P.B.L. An Experimental System for Auditory Image Representations, *IEEE Transactions on Biomedical Engineering*, Vol. 39, No. 2, pp. 112-121, February 1992.
- [6] Kay, L. Auditory Perception of Objects by Blind Persons Using Bioacoustic High Resolution Air Sonar. *JASA*, Vol 107, pp 3266-3275, No 6, June 2000.
- [7] Kaczmarek, K.A. and Bach-y-Rita, P, Tactile Displays, in *Virtual Environments and Advanced Interface Design*, Barfield, W. and Furness, T., Eds. New York: Oxford University Press, pp. 349-414, 1995.
- [8] Meers, S. and Ward, K.: "A Vision System for Providing 3D Perception of the Environment via Transcutaneous Electro-Neural Stimulation", *Proceedings of the 8th IEEE International Conference on Information Visualisation*, London, pp 546-552, July 2004